UNIVERSIDAD CARLOS III DE MADRID

ESCUELA POLITÉCNICA SUPERIOR

AUDIO SYSTEM BASED ON ANALOG ELECTRONICS: SIGNAL PROCESSOR AND VALVE AMPLIFIER

Bachelor Thesis

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AGRADECIMIENTOS

A mis padres, a mis abuelos y a toda mi familia por todo el apoyo recibido.

A mi tío Luis por todo lo que me ha enseñado.

A mis amigos por estar en los buenos y malos momentos.

A mi tutor, Jorge, por aceptar mi propuesta y ayudarme a sacar adelante este proyecto.

A Juan por ayudarme en la elaboración de uno de los prototipos.

A todas las personas que me han apoyado a lo largo de todos estos años.

INDEX

1. INTRODUCTION

• Socio-Economic Setting

The main motivation of this project is to connect the world of engineering with the world of emotions. We find ourselves in a world where everything tends to be digital and analog systems are disappearing. But there are a number of applications and sectors were analog systems still have a place, one of which is the sound engineering and sound systems.

- Socio-Economic Impact

Although there are many digital systems that are very compact and include lots of functionalities, there still are a lot of consumers that prefer an analog system with less functionalities but a better quality and robustness.

But there is also a special bound that emotions create with this kind of analog systems in certain sector like entertainment. Specially when we talk about sound and more specifically on music applications, certain sounds produced by some systems create an emotion that is difficult to imitate with a digital system. Maybe it is due to an association in our brain with certain recordings of the past where there only where those kinds of systems. We do not know the reason but the reality is that there are plenty of analog systems that are built nowadays and sold in the market.

In this project, we want to explore some systems that produce a special feeling when they are used. We want to value systems which are not perfectly compact or efficient but have a special characteristic which makes us feel something that is difficult to explain with words.

There are many people that prefer to have the digital versions, which are more compact, of many audio systems like an amplifier, or a special signal processor or effect. But we want to defend that there are still many others who prefer to have, at least for some applications, analog systems that provide them better quality and feeling.

The principal impact of this project is that we will have a system which can be built, and we will build it. This will give us the opportunity of creating a product from it and sell it in the market. We can take profit of it and provide with this system to the people that are interested in analog systems of the said characteristics.

In many online stores, or physical stores, we can find a huge variety of analog systems. This means that there is still a market that demands this kind of systems and uses them.

- **Bachelor Thesis Budget:**

These are the costs of the Valve Amplifier prototype:

Description	Amount (€)
Wood board	4.66
Electronic Components	6.36
ECL85 (triode-pentode valve)	7.73
Power Transformer (220-125V)	17.36
Electronic components	13.31
Regulated Voltage Source	22.11
Total	**71.53**

Table 1

- **Proposal**

The goal of this project is to design and assembly an audio system based on analog electronics which can have several applications. The purpose is to design and assembly a modular audio system, this means that we will have different subsystems that can be used independently or connected together. Concretely, we will have two subsystems, a signal processor and an amplifier based on one valve, each one with one input and one output. We will be able to introduce an audio signal at the input and obtain an output audio signal on each subsystem. We have two options:

1. We can connect both systems together in the following way:

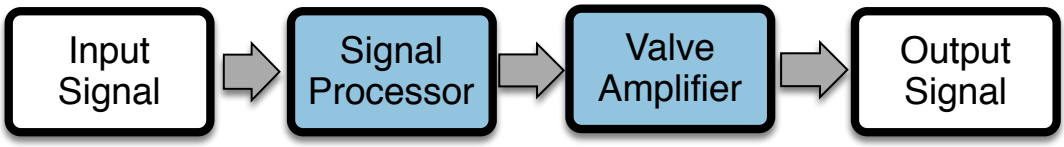


Figure 1

2. We can connect the systems independently:

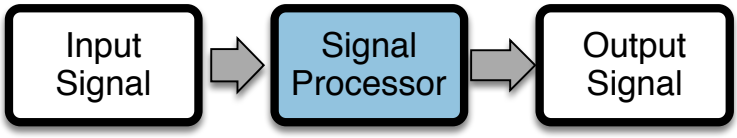


Figure 2

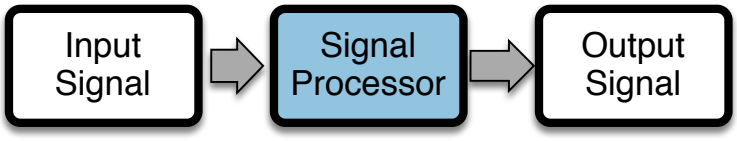


Figure 3

One of the main applications of this system, and the subsystems by themselves, is to use as input the output of an instrument, for example an analog synthesizer, a guitar, a keyboard or just a microphone.

- **Signal Processor**

A lot of audio systems have an effect unit before the output stage. If we take a look at the basic scheme of an analog synthesizer, which is an electronic musical instrument that can be played, the main parts are:

- **Oscillator/VCO:** circuit that creates the initial signal that will generate the sound. It has more than one type of waveform and it is usually based on an oscillator, specifically a VCO (Voltage Controlled Oscillator).
- **Filter/VCF:** Voltage Controlled Filter to remove the unwanted parts of the signal. It can have a band pass filter, low pass filter or high pass filter, or all of them.
- **Amplifier/VCA:** Voltage Controlled Amplifier with controllable gain to give the desired level at the output.
- **ADSR:** to produce the envelope of the signal. There may be more than one to control the filter and the amplifier envelopes.
- **Keyboard:** to play the instrument and select the frequency that the synthesizer generates every time. It can include some buttons to increase or decrease the octave and also pitch and modulation modifiers.
- **LFO:** Low Frequency Oscillator to generate variations on the signal like vibrato or tremolo for example.
- **Noise:** It can include a noise generator.
- **FX unit:** to introduce some effects like reverb or delay to the signal, so it doesn't sound so dry.

In the following figure, we can see the basic scheme of a synthesizer.

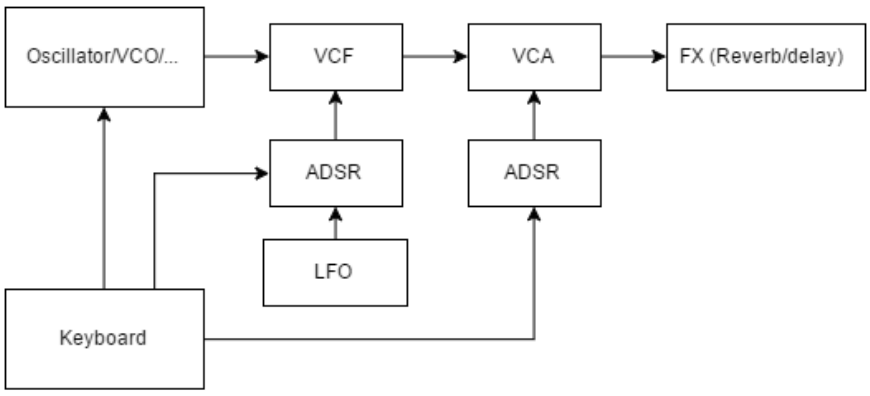


Figure 4

There are two types of synthesizer depending on how we connect each subsystem on it: we can have a modular synthesizer, if we have each subsystem as an independent system that we can connect as we desire, or we can have a synthesizer that is already

routed and we cannot modify the path of the signal. Nowadays, we can find some synthesizers that have both options.

The first subsystem of our project, can be used, for example, in the Effects Unit (FX Unit) of an analog synthesizer.

We will analyze the Arturia Minibrute Saw Animator or Ultra Saw unit. The Arturia Minibrute is an analog synthesizer that has the basic elements we described before and some more.

Figures 5 & 6: https://www.arturia.com

The original circuit operation consists of adding two phase shifted replicas of the original Saw signal to the original signal itself, creating a special sound by increasing the harmonics in the signal. The phase of the replicas is changing constantly. We can vary the modulation rate of the phase-shifted replicas independently.

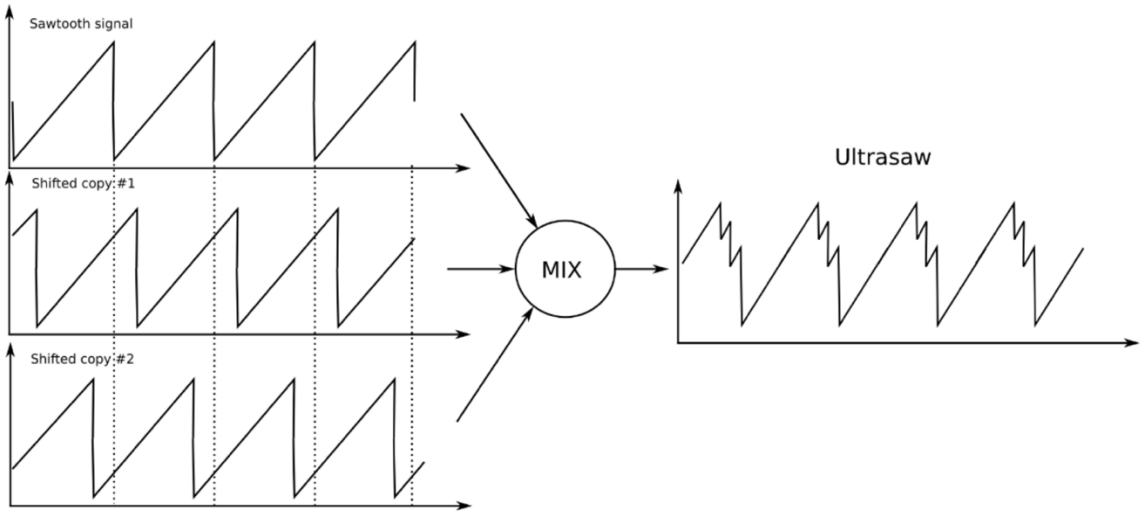


Figure 7: Arturia Minibrute Manual

We will adapt this system to be able to connect any input signal and not only a saw-tooth waveform coming from the oscillator, as in the original circuit.

- **Valve Amplifier**

Most of the audio systems need an output stage in order to give power to the speaker at the end. We can have several types of amplifiers in this output stage, but we will design and assembly a Valve Amplifier that gives some characteristics to the sound that are very difficult or almost impossible to achieve with other kinds of amplifier. We will base our circuit in some designs that we will comment later, but the purpose is to build a mono output stage based on one single valve.

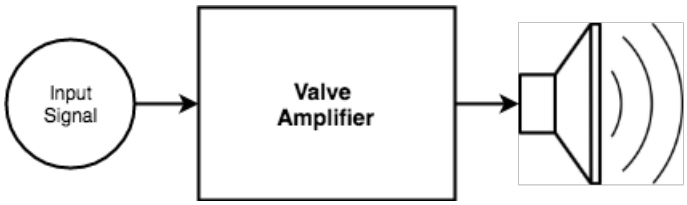


Figure 8

• State of the art

In this part, we will see some systems that are already in the market and present similar characteristics to the one we want to build.

- **Signal Processor**

There are plenty of systems for audio applications that process the signal and include effects, adding a special characteristic to the signal. We can have for example reverb, delay, chorus, flanger and many more. Here we show an example of a reverb unit and a delay:

Figures 9 &10: https://www.thomann.de

Some systems include this units inside, without the need of having an additional device. As we said before, we are going to focus on the Arturia Minibrute Ultrasaw effect unit which is located inside said synthesizer.

- **Valve Amplifier**

Typical examples of Valve Mono Amplifiers are most of the Marshall amplifiers, widely used for guitars and other instruments:

Figures 11 & 12: https://marshallamps.com

But Valve Amplifiers are not only used for instruments. We can use this type of amplifiers in hi-fi systems for domestic use:

Figures 13 & 14: https://www.thevinylfactory.com & http://cdn.audioaffair.co.uk

- **Policy framework**

We are going to show how the CE marking works in the European Economic Area. In the European Commission website, we can read the following:

"The letters 'CE' appear on many products traded on the extended Single Market in the European Economic Area (EEA). They signify that products sold in the EEA have been assessed to meet high safety, health, and environmental protection requirements. When you buy a new phone, a teddy bear, or a TV within the EEA, you can find the CE mark on them. CE marking also supports fair competition by holding all companies accountable to the same rules."

Figure 15: https://ec.europa.eu/growth/sites/growth/files/ce-mark.png

The general principles of the CE marking are:

1. *“The CE marking shall be affixed only by the manufacturer or his authorised representative.”*

2. *“The CE marking shall be affixed only to products to which its affixing is provided for by specific Community harmonisation legislation, and shall not be affixed to any other product.”*

3. *“By affixing or having affixed the CE marking, the manufacturer indicates that he takes responsibility for the conformity of the product with all applicable requirements set out in the relevant Community harmonisation legislation providing for its affixing.”*

4. *“The CE marking shall be the only marking which attests the conformity of the product with the applicable requirements of the relevant Community harmonisation legislation providing for its affixing.”*

5. *“The affixing to a product of markings, signs or inscriptions which are likely to mislead third parties regarding the meaning or form of the CE marking shall be prohibited. Any other marking may be affixed to the product provided that the visibility, legibility and meaning of the CE marking is not thereby impaired.”*

6. *“Member States shall ensure the correct implementation of the regime governing the CE marking and take appropriate action in the event of improper use of the marking. Member States shall also provide for penalties for infringements, which may include criminal sanctions for serious infringements. Those penalties shall be proportionated to the seriousness of the offence and constitute an effective deterrent against improper use.”*

If we want to commercialize these systems, we will need to accomplish these rules given by the CE marking.

2. SOLUTION APPROACH

- **Signal Processor**

The solution is based on the Arturia Minibrute Ultra Saw effect:

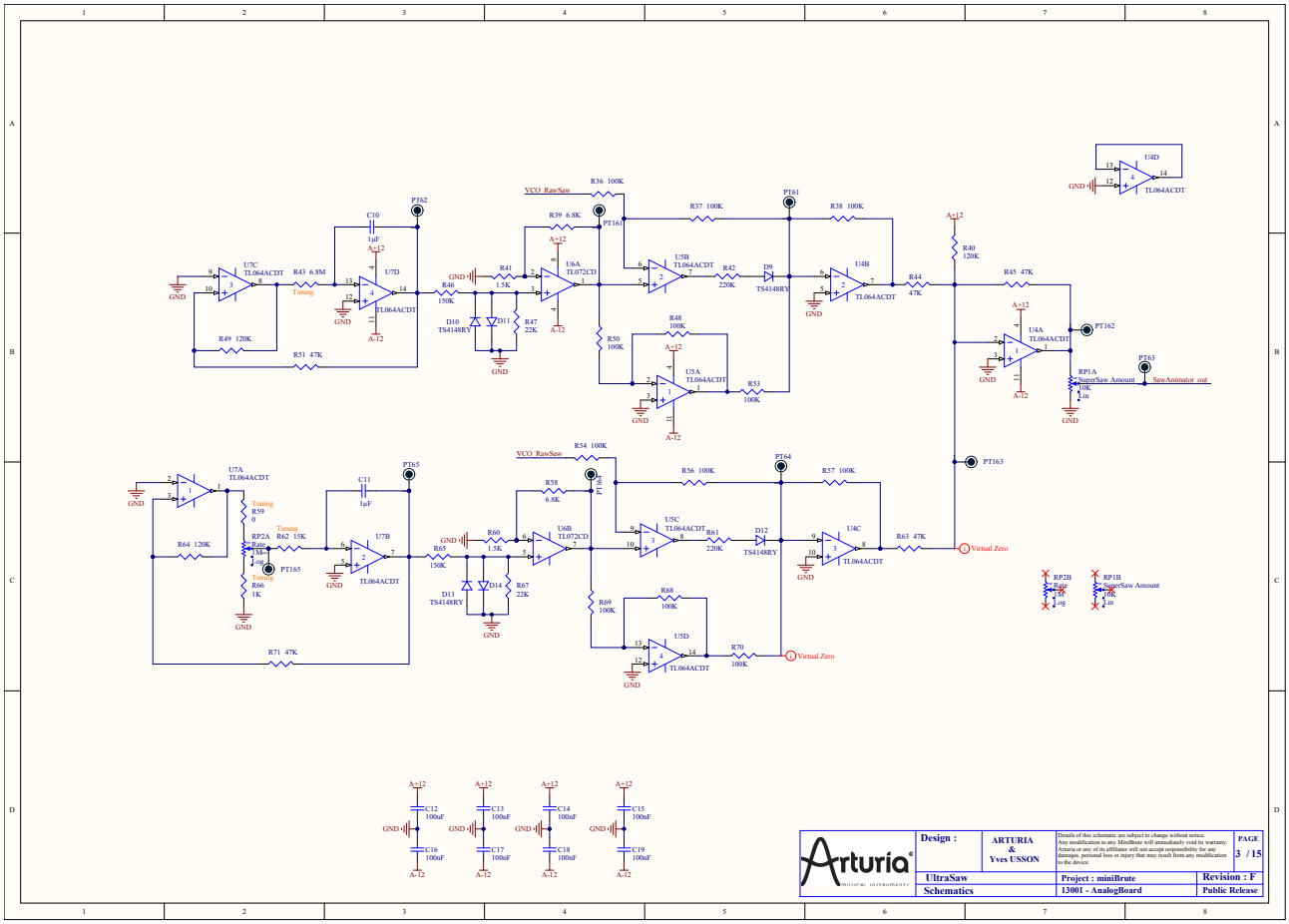


Figure 16: Hack a Brute web site

We will analyze and assembly the circuit, in order to learn how it works and make some modifications.

- **Valve Amplifier:**

We will analyze and build a mono output stage based on one valve. We will use the ECL85 triode-pentode valve to build a mono amplifier with a power of approximately 9 Watts. We will base our circuit in the following design:

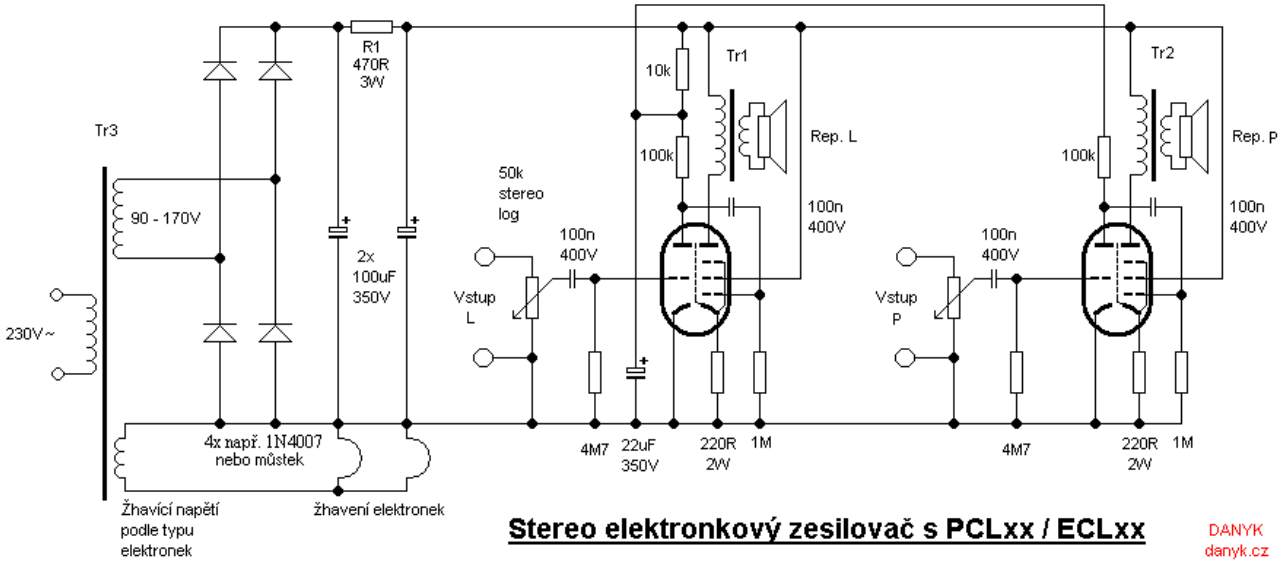


Figure 17: http://danyk.cz/

It is a stereo valve amplifier that can be used with all the PCLxx and ECLxx family of valves.

As our intention is to describe the basic operation of a valve amplifier, we will only use one of the channels for the prototype. If we want to build the stereo version, we just need to copy the same scheme.

3. DEVELOPMENTS

- **Signal Processor**

It consists of a circuit with two symmetric parts and a mixer.

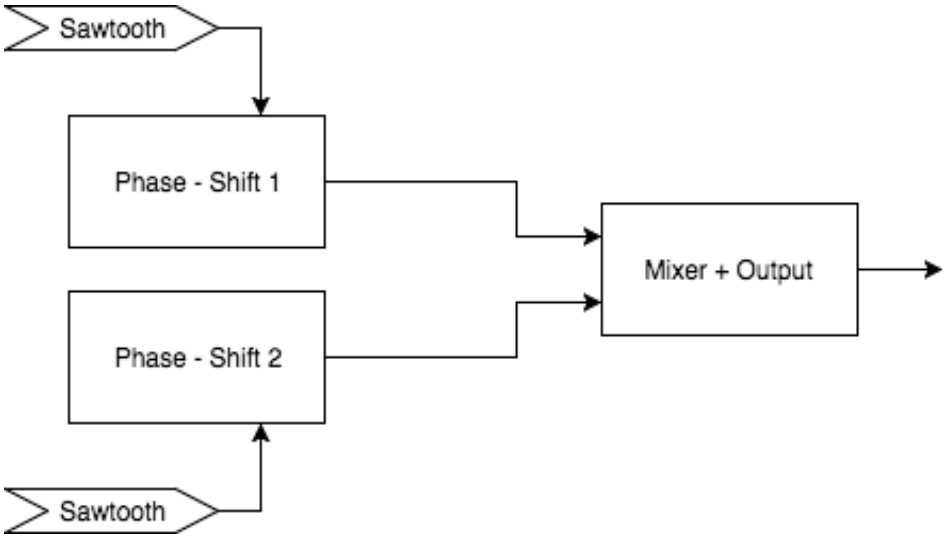


Figure 18

We are going to describe one of the circuits that produce the phase-shifted replica (Phase - Shift 1), the other one is exactly the same.

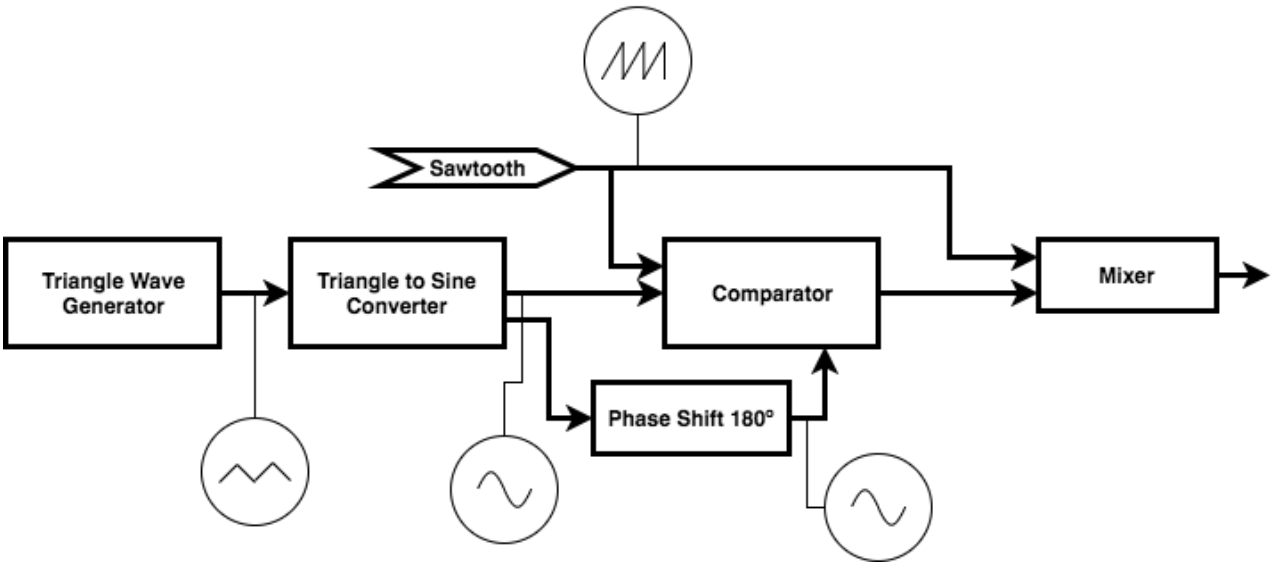


Figure 19

- **Triangular Wave Generator:**

At the beginning of each part we have a triangular and square wave generator based on a comparator with hysteresis:

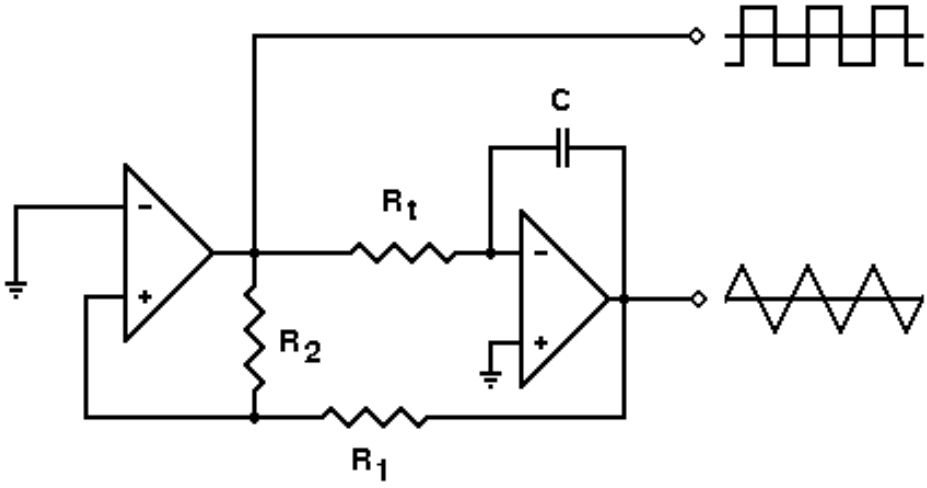


Figure 20: allaboutcircuits.com

$$f_{out} = \frac{1}{4R_tC}\left(\frac{R_2}{R_1}\right)$$

We can tune the frequency of both signals, square and triangle, by changing the value of Rt. The advantage of this circuit is that we can change the frequency with any variation in the amplitude of the output signal.

- **Triangular to Sine Converter**

The circuit is followed by a triangular to sine converter. The goal of this part is to transform a triangular waveform into a sine waveform using the dynamic resistance (Rd) of the diodes in antiparallel configuration.

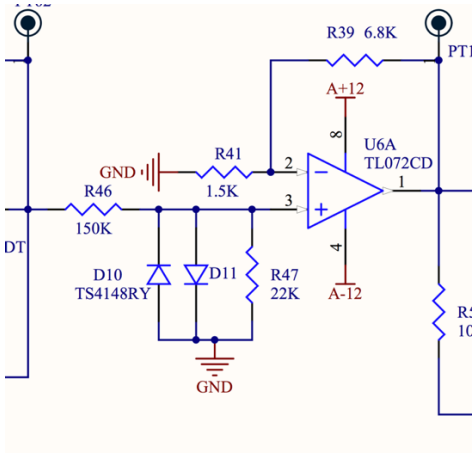


Figure 21: Hack a Brute web site

- **Comparator stage:**

Following the triangle to sine converter stage, we have a comparator, which is the one in charge of introducing the phase shifted replica to the input signal:

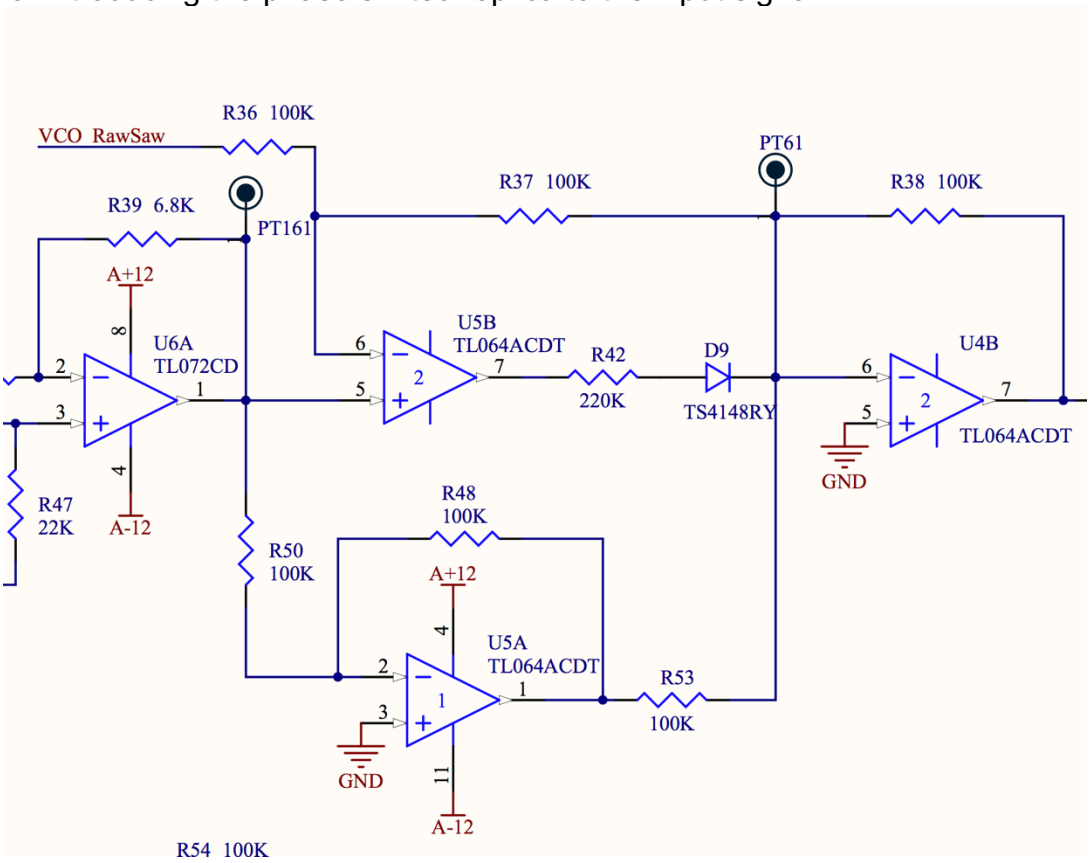


Figure 22: Hack a Brute web site

The operational amplifier (U5B) works as a comparator. In the negative input, we have the input signal, while in the positive input we have the sinusoidal signal that comes from the triangular to sine converter. The circuit below, formed by three resistors and an operational amplifier (U5B), introduces a phase shift of 180º to the sine signal.

As we are constantly changing the voltage level of both inputs of the comparator, we have a PWM signal at the output of the operational amplifier U5B. This makes the diode D9 go ON and OFF at a rate given by the sine signal.

Depending on the state of the diode D9 we have two different situations:

- $\boxed{D_{on}}$

So, we have the following elements working in the circuit:

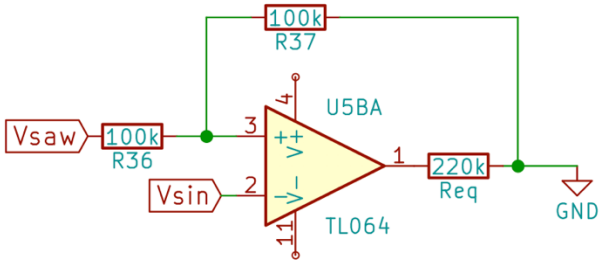


Figure 23

Req corresponds to the equivalent resistance of the Diode and the resistor R42.

$$\frac{V_{SAW} - V_{SIN}}{100k\Omega} = \frac{V_{SIN}}{100k\Omega} \Rightarrow \boxed{V_{SIN} = \frac{V_{SAW}}{2}}$$

- $\boxed{D_{off}}$

In this case we have the following:

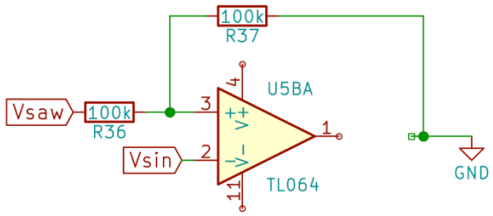


Figure 24

So, the signal at the output will be the current coming from the input.

- **Mixer:**

After this circuit, we have a mixer that is adding the currents that come from both situations, because the operational amplifier output is connected to ground and it does not have any information about the voltage. In the first situation, the amplitude of the current is half of the one given by the input. So, we will be introducing the same signal but with half the amplitude. In the second case, the signal we introduce is the same as the input signal. As the frequency of the input signal is higher than the oscillation between these states, given by the sine signal, we will be adding to the original signal a new replica of itself but with half the amplitude.

• Valve amplifier

The purpose of this part is to design and build a simple mono amplifier based on one valve and explore its sound characteristics. But before, we need to understand how an Electronic Valve works and how can we take advantage of its properties to build an audio amplifier.

- **The Electronic Valve:**

Let us talk about the history of this electronic device. It was the beginning of the nineteenth century, when Davy managed to illuminate a platinum plate, causing an electric current to pass through. The century of inventions was still running, and in 1879, Edison marketed an incandescent lamp that had the filament made of carbon.

Tomas Alva Edison observed that the glass of the lamps with which he was experimenting, became more and more blackened to the phenomenon he called "Edison effect", today we call it thermionic emission. Later he placed a plate to avoid the annoying phenomenon, when he applied a properly polarized voltage, he noticed that an electric current was flowing through the circuit, he could not explain the physical phenomenon when he had actually discovered or invented the rectifying diode or diode valve.

A few years later, at the beginning of the twentieth century, Fleming used the diode as a detector element, and little by little there were appearing more and more applications to this valve rectifier or trimmer. All these investigations were developing the valve more and more, when introducing some electrode between the already existing ones. The triode, the tetrode, the pentode and more started to appear.

- **The Vacuum Valve**

The free electrons can be obtained by photoelectric effect, secondary electronic emission or thermionic emission. The vacuum valve is based on the last one, the thermionic emission, so we will focus on this one.

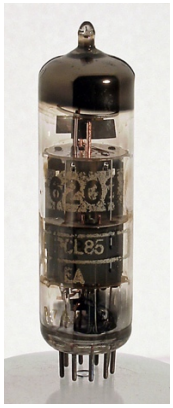


Figure 25: ECL85 Datasheet

- **Thermionic Emission**

Free electrons are in continuous and arbitrary motion, constantly passing from the periphery of some atoms to others. But at regular temperature, the speed of these free electrons is not enough to achieve the detachment of them, to leave the conductor of which they are part of. However, by heating certain metal conductors under certain conditions, the emission of free electrons coming outwards can be achieved from 600 ° C approximately.

This phenomenon of the electrons being released by the effect of the heating, is analogous to the evaporation of the molecules of a liquid when it is heated strongly until the boiling.

In thermionic or electronic valves, the element or electrode that produces this emission of electrons is called the emitter or the cathode.

There are two ways of producing cathodic emission, direct heating and indirect heating:

Direct Heating

Direct heating by cathode-filament was a type of heating which was used in the primitive valves. A filament composed of tungsten was heated, up to about 2500 ° C, in order to obtain the electronic emission. Heating is achieved by an electric current that flows through said filament.

Indirect Heating

The indirect heating consists of circulating the heating current by an independent heater, without electrical connection of the heat source, in this case of the filament.

Therefore, the cathode or emitter electrode is isolated from the filament, but is heated by it and finally produces the thermionic emission. It consists of a tube generally made of nickel, coated with barium and strontium oxides that have a great emitting power, which is already achieved with a temperature of about 900ºc to 1000ºc.

They become deteriorated faster than those of tungsten when suffering ionic bombardment and having to withstand great ionic stresses. However, they almost are the only type of valves used amplification applications.

The Diode

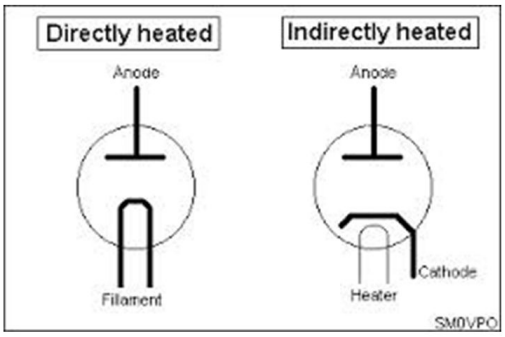


Figure 26: http://slideplayer.com

In both types of heating, the number of electrons that can be emitted, that is, the maximum possible current, is called the saturation current, which depends on the constituent material of the surface of the emitting cathode and the heating temperature.

The electronic valves could be described as an element that is formed by a glass ampoule and different electrodes inside that compose it. According to the number of electrodes that make up a valve, it is called in different ways:

- Diode: two electrodes.
- Triode: three electrodes.
- Tetrode: four electrodes.
- Pentode: five electrodes, and so on.

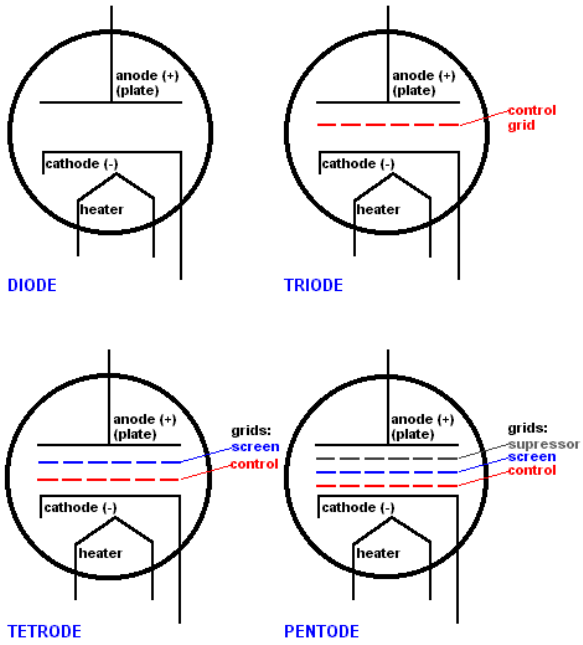


Figure 27: http://cf.ydcdn.net/

The filament does not count as an electrode for the indirect heating valves.

It is necessary to speak of the utility of the vacuum in the thermionic valves, the extraction of the air from the glass ampoules is necessary, in order to eliminate the oxygen that would determine the combustion of the filament when heating and to become incandescent. The vacuum is also useful to clear obstacles constituted by the molecules of gas, enabling the way that the electrons have to run from the cathode to the place of destination that will be discussed later.

As the air or other gas molecules are bombarded by electrons at high speed, they dislodge one or more electrons from the atoms at the same time as they give rise to positive ions that are attracted strongly by the cathode, which as a consequence of the collisions are weakened and can shorten their duration.

- **The Diode Valve**

They are the simplest type of valves. Although the electronic emission of a hot metal body was already discovered by Edison in 1884, no practical results were obtained until 1904 in which Fleming patented the diode to be used as a detector of received radiotelegraph signals.

We will now deal with high vacuum thermionic emission diodes. We present the basic operating circuit in the following figure:

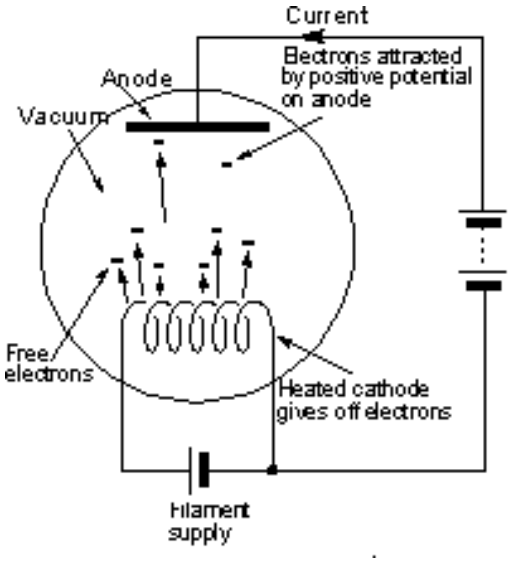


Figure 28: https://i.pinimg.com

It is accompanied by what is called diode characteristic curves. These curves represent the actual operation of a diode as a function of the different plate polarizations and heating of the emitter cathode.

As we see, the diode consists of two electrodes, the cathode and the plate or anode. In this case of indirect heating, we have the independent heater or filament, but it is not considered, as already mentioned above, as an electrode. Around the cathode, when heated, a cloud of electrons is produced which is called the spatial charge. These electrons that surround the cathode, tend to oppose new exits of electrons emitted by this one. The phenomenon disappears when we apply to the plate a positive potential, enough to attract the electrons towards it, from then, an electronic current begins to take place through the plate circuit.

- **Characteristic curve of a diode valve:**

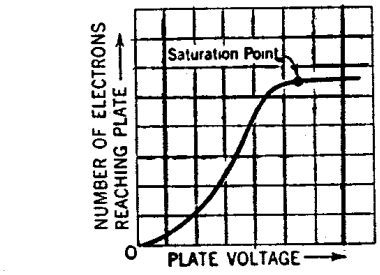


Fig. 5—Current characteristic of diode tube.

Figure 29: http://vrps.org/

The characteristic curve of the diode, corresponds to a determined cathode temperature, varying the plate voltage and observing the increase of the current through the plate.

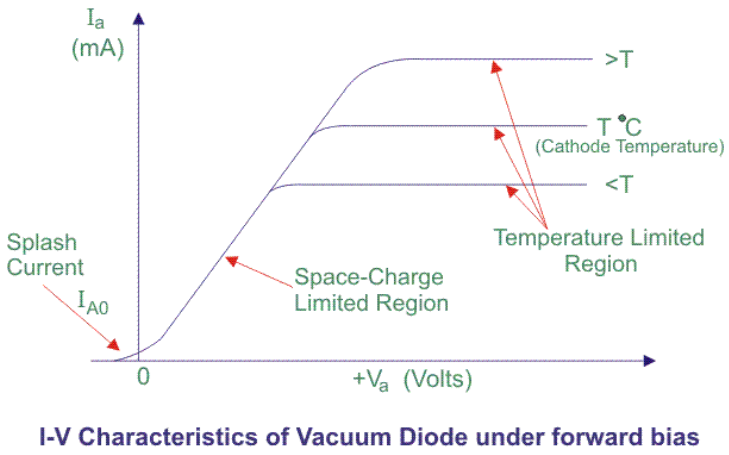


Figure 30: https://www.electrical4u.com

Diode characteristic curve if we vary the temperature of the emitting cathode. As we increase the temperature of the cathode, the saturation is reached at a higher current point.

We can say that in the normal operation of the diode, that is, before reaching the saturation current, the value of Ip (current through the plate) is a function of Vp (Voltage in the plate). But when we have reached the value Ip = Is (saturation current), to increase Ip it is necessary to increase the value of T (cathode temperature).

- **Unique sense of electrons circulation property**

The diode valve allows the current to flow in a single direction, that is, from the cathode to the plate. The name “Electronic Valve” comes from this property, given to the diode and other devices, with more electrodes, that derive from it.

- **The diode valve as rectifier**

When applying an A.C. voltage between the cathode and the plate we have:

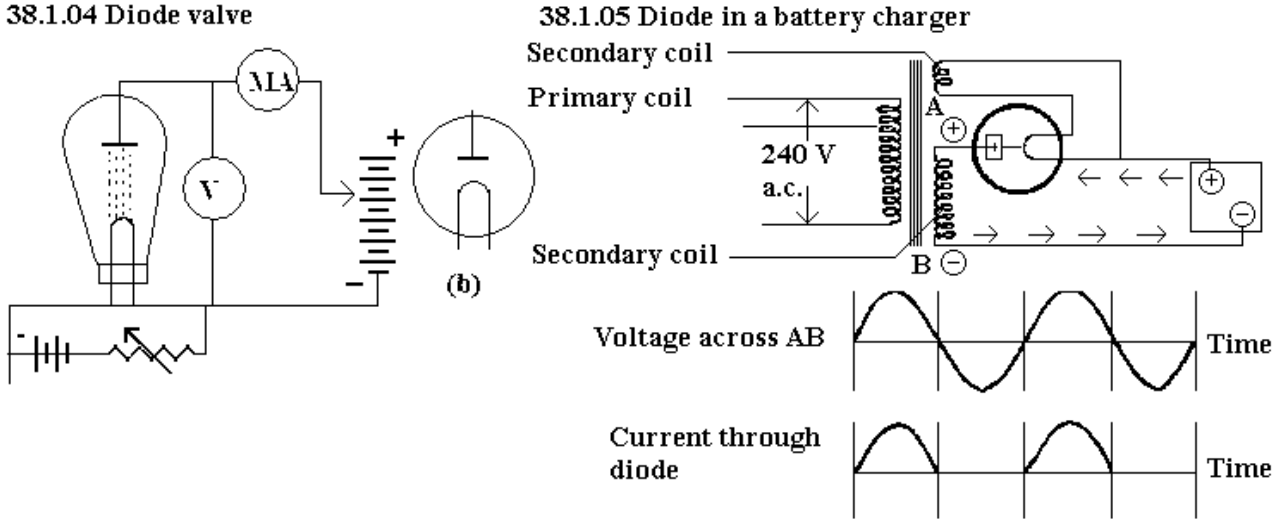


Figure 31: http://www.uq.edu.au

The valve becomes conductive only when the potential of the plate is positive relative to the cathode. Therefore, current only flows in one direction. So, by applying A.C. current to the valve, we will obtain D.C. or rectified current. After the rectification, the negative half-cycles of the C.A are canceled.
From the properties of the diode just indicated, its application as a "rectifying device" of current is deduced, making it possible to feed the plates and other electrodes, like screens, of the different valves of a radio or television receiver, with the alternating current of network.

- **Diode Valves as half-wave rectifier**

In the figures shown below, we see an example of a half-wave rectifier circuit with indirect heating, in addition to the operation graphs of a half-wave rectifier:

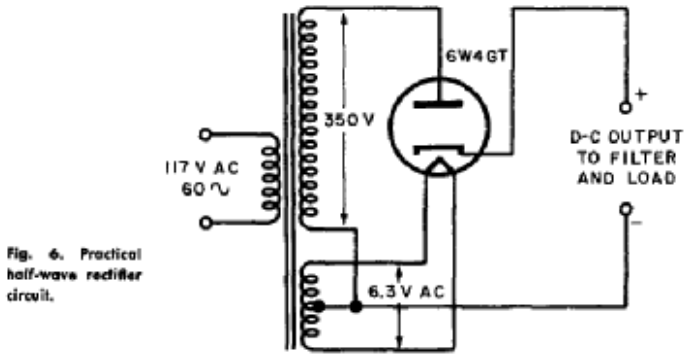


Figure 32: http://www.radiomuseum.org

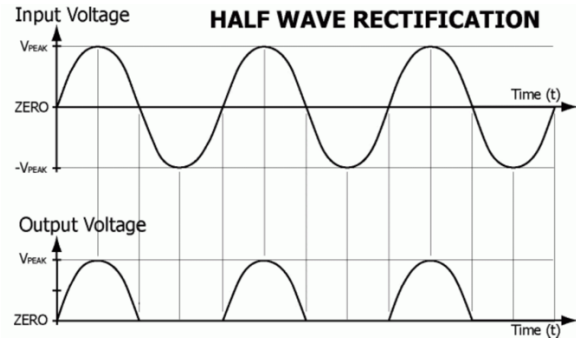


Figure 32: https://ibphysicsnotes.files.wordpress.com

- **Diode Valves as full-wave rectifier**

The following figure shows a full-wave rectifier circuit consisting of two diodes, the first of which rectifies the positive cycles and the second the negative ones.

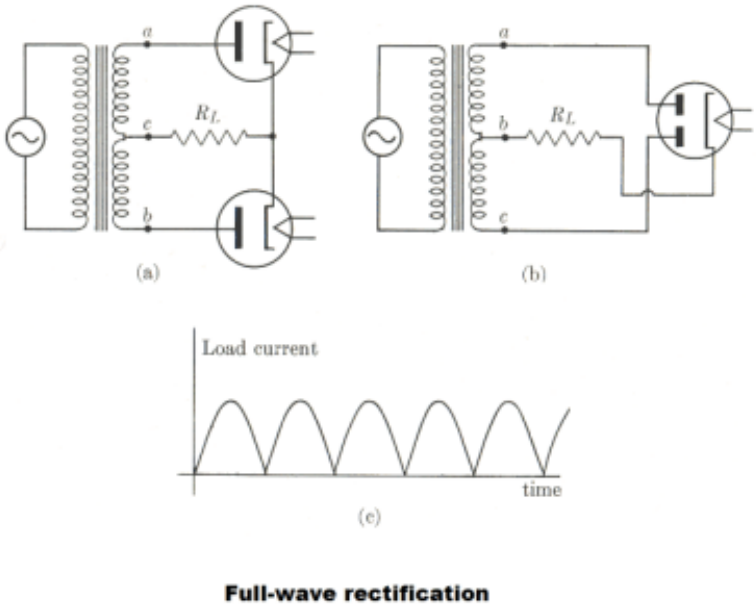


Figure 33: http://www.solitaryroad.com

In order to obtain continuous current, we need to complete the rectifier circuit by using a filter. We can use a Pi-filter to remove the voltage variations. In the following figure, we can observe an example (the filaments of the diode valves are not shown and we assume we have indirect heating):

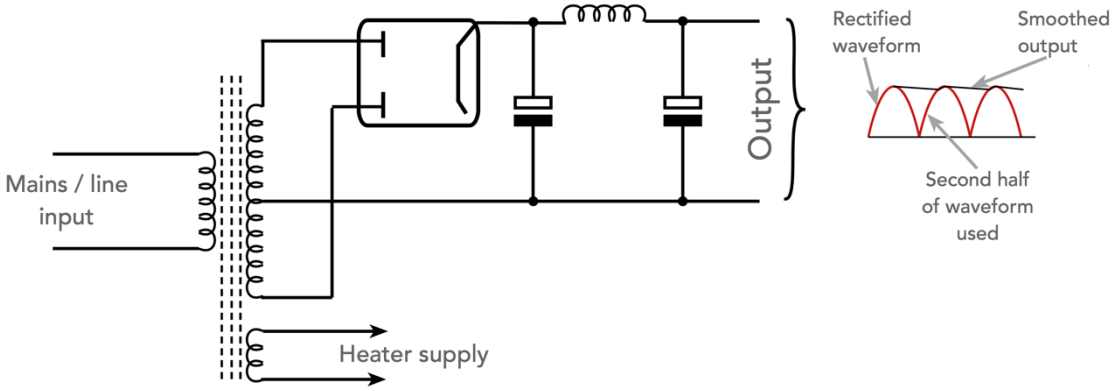


Figure 34: https://www.electronics-notes.com

- **The Triode Valves**

In the triode valve, in addition to the cathode and the anode, there is a third electrode in the middle which is called a grid. This third electrode is used to control the current of electrons through the valve, that is, to control the anode current without changing the voltage applied to the latter.

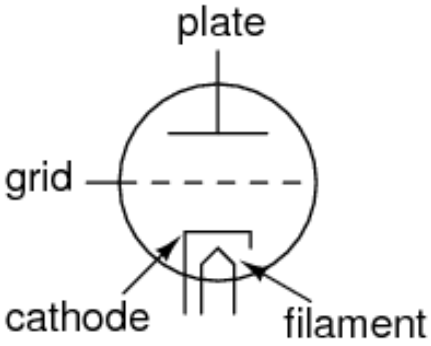


Figure 35: https://sub.allaboutcircuits.com

When the grid changes its voltage relative to the cathode we have different situations:

1- If the grid is neutral or has the same voltage as the cathode, the valve will practically behave like a diode, as if the grid did not exist and therefore not influencing the current of the plate.
2- When the grid is negative, relative to the cathode, the plate current decreases and may become zero.
3- When the grid becomes positive relative to the cathode, the plate current increases, until a moment when it is no longer possible to increase it more, it is said that the valve has reached saturation point.
4- When the positive grid is made relative to the cathode, a new current in the grid-cathode circuit appears and gradually increases as the positive grid voltage increases

- **Characteristic curves of a triode valve**

Here we have an example of a simple amplifier circuit using a triode valve:

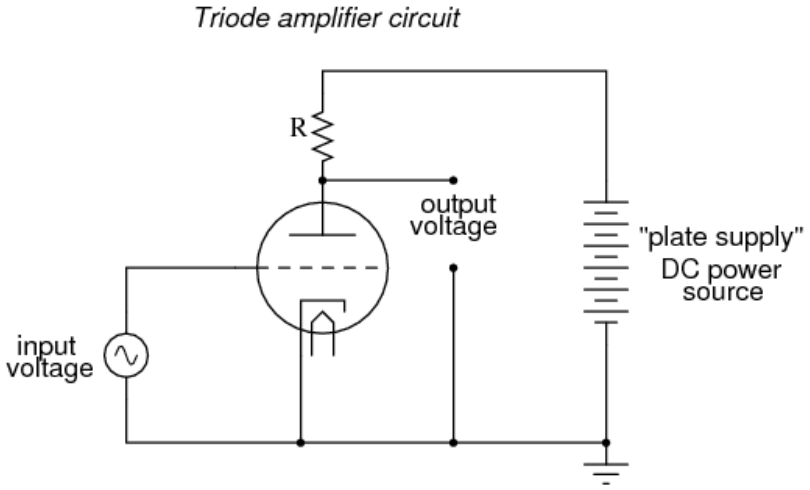


Figure 36: https://www.ibiblio.org

Using this circuit, we can obtain the characteristic curves of the triode valve:

- **Static Grid Curves:**

We obtain each of the characteristic curves by applying a certain plate potential or anode potential (Vp or Va), giving different values to the grid voltage (Vg) and noting the corresponding values taken by the plate current (Ip).

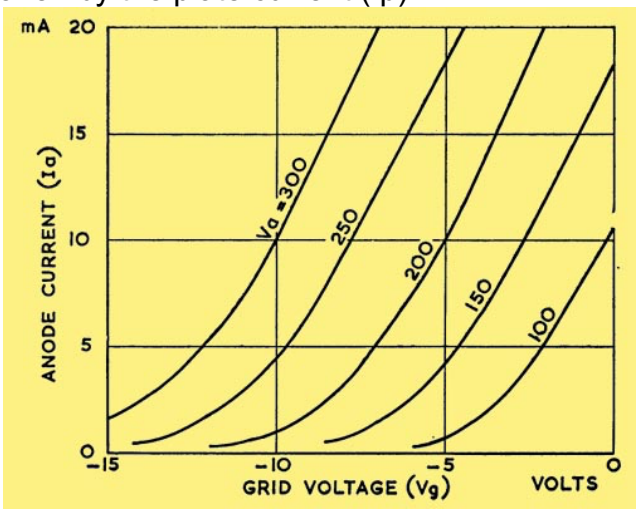


Figure 37: http://www.r-type.org

In the following figure, we can see the grid curve for the triode inside the ECL85 triode-pentode valve:

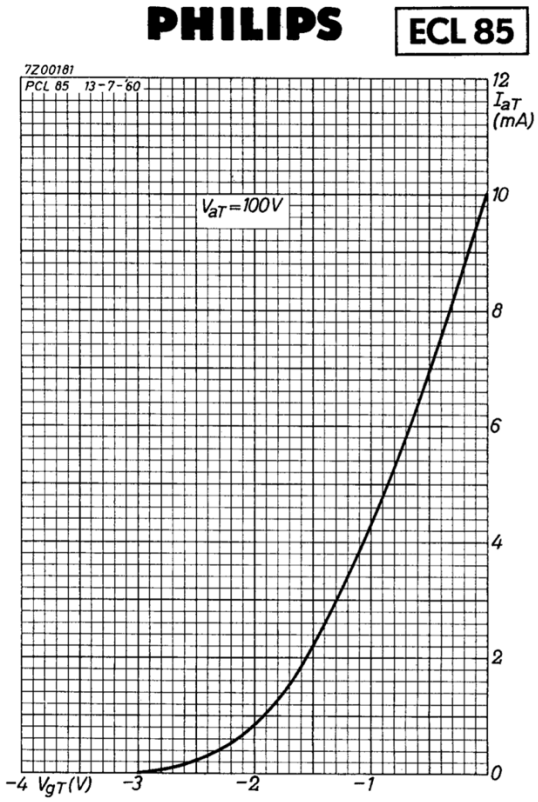


Figure 38: ECL85 Philips Datasheet

- **Static Plate Curves:**

The static characteristics curves of the plate are shown in the following figure.

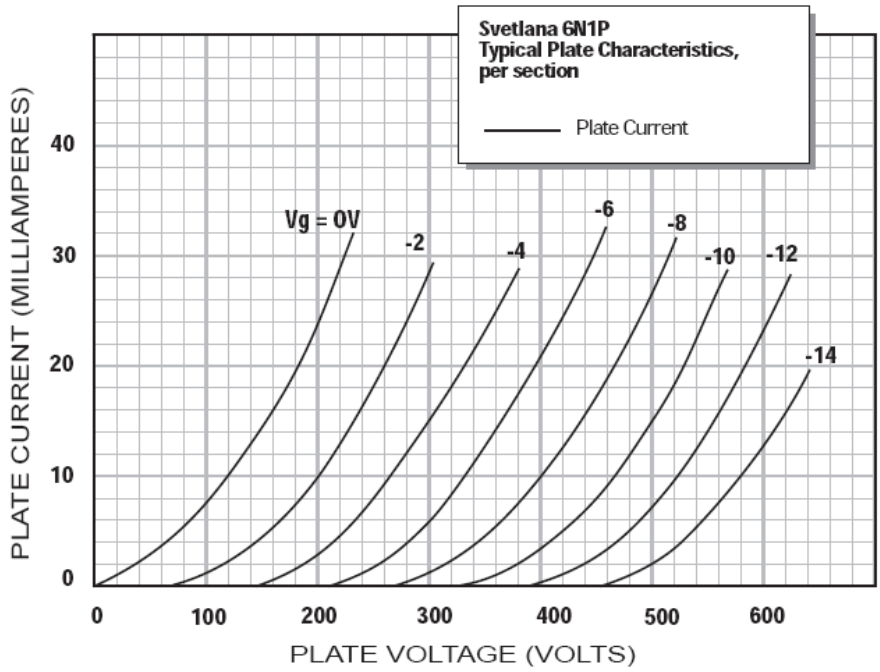


Figure 39: http://www.mqcvisions.net

By means of the same circuit we saw before, we can now obtain these other curves. Here we keep the grid tension (Vg) constant, while we vary the plate voltage or anode voltage (Vp) attain each of the curves constituting the family.

We can observe the static plate curves of the same triode we saw before:

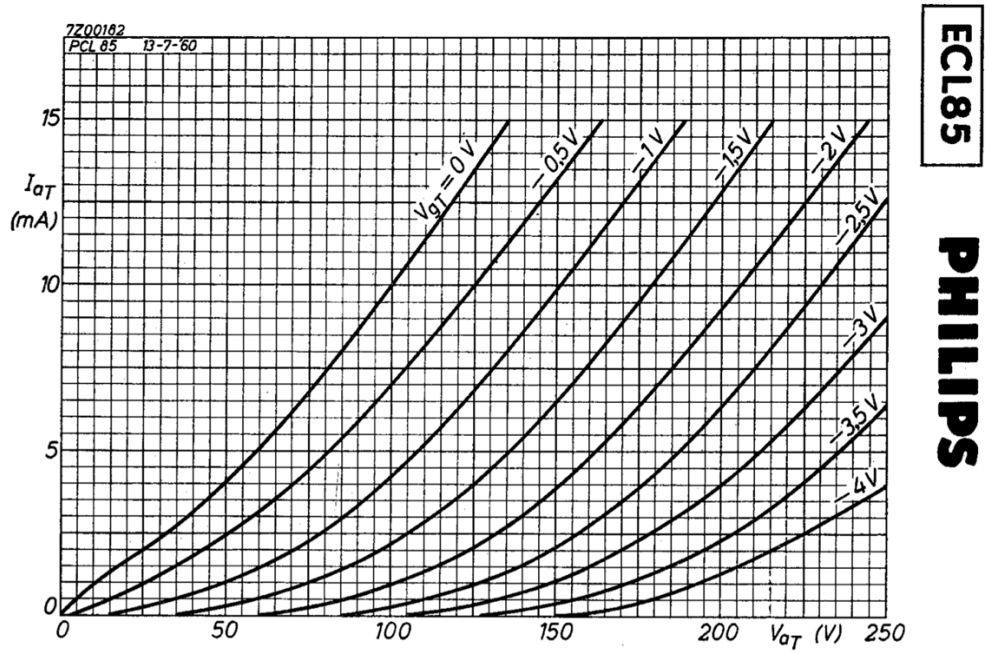


Figure 40: ECL85 Philips Datasheet

- **Characteristic coefficients of the triode valve**

The characteristic coefficients of the triode valve are three:

1- Internal resistance, Ri: also called plate resistance, will be obtained for any triode, dividing a variation of the plate voltage by an increase or variation of the plate current, remaining the grid voltage constant:

$$R_i = \frac{\Delta V_p}{\Delta I_p} \ [\Omega]$$

Taking Vp in Volts and Ip in Amperes, we obtain Ri in Ohms.

2- Amplification factor, μ: can be defined as the number of volts we need to vary of the plate voltage in order to have a variation of one volt in the grid voltage.

$$\mu = \frac{\Delta V_p}{\Delta V_g} \ \left(I_p = constant\right)$$

The value of μ depends on the ratio between the cathode-grid and cathode-plate inter-electrode capacitances:

$$\frac{C_{kg}}{C_{kp}}$$

So, the amplification factor increases as we bring the grid closer to the cathode and move the plate away from it, or by increasing the surface of the grid.

3- Slope, mutual conductance or transconductance, S, P or Gm: is the variation of the plate current, for each Volt of variation of the grid voltage, fixing the plate voltage to a certain value.

$$P = S = G_m = \frac{\Delta I_p}{\Delta V_g}\left[\frac{mA}{V}\right][m\Omega^{-1}](V_p = constant)$$

The slopes are expressed in Milliamps per Volt or Millimhos.

- **Dynamic operation of the triode valve**

In order to analyze the dynamic operation of the triode valve we can take a look at the following circuit:

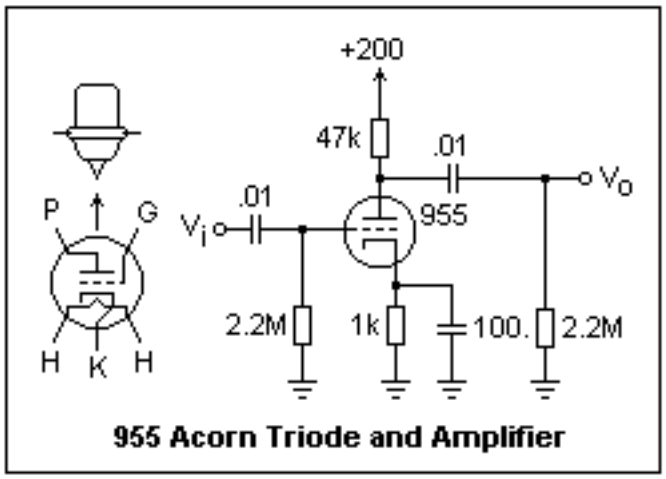


Figure 41: https://mysite.du.edu

In the next figure, we represent the variation that occurs in the plate current for a variation of the voltage applied to the grid. We can see that in the circuit of the plate there is an alternating current with a D.C. offset, which is an exact reproduction in the frequency and waveform of the alternating voltage Vg applied between the cathode and the grid.

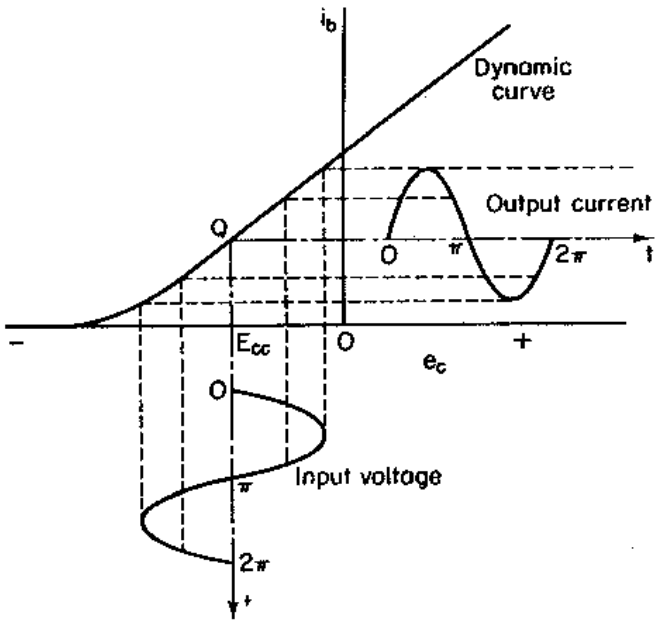


Figure 42: http://livinginthepast-audioweb.co.uk/

We need a capacitor to remove the D.C. offset that the input signal could have, in order to prevent the grid bias voltage from being altered.

Depending on how we amplify the signal, that is, in which dynamic region we are, we have the different kinds of amplifiers:

- **Class A Amplifier**

In this type of amplifier, the operating point of the valve always moves in the straight region of the characteristic curve, therefore the plate current is not zero at any time.

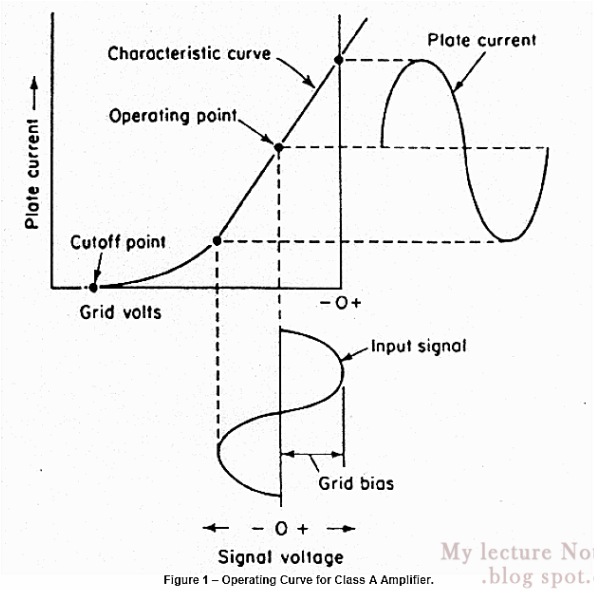


Figure 43: http://4.bp.blogspot.com/

- **Class AB Amplifier**

In this case, the grid polarization and the applied alternating voltages are such that the plate current flows more than half a cycle, but less than the complete cycle.

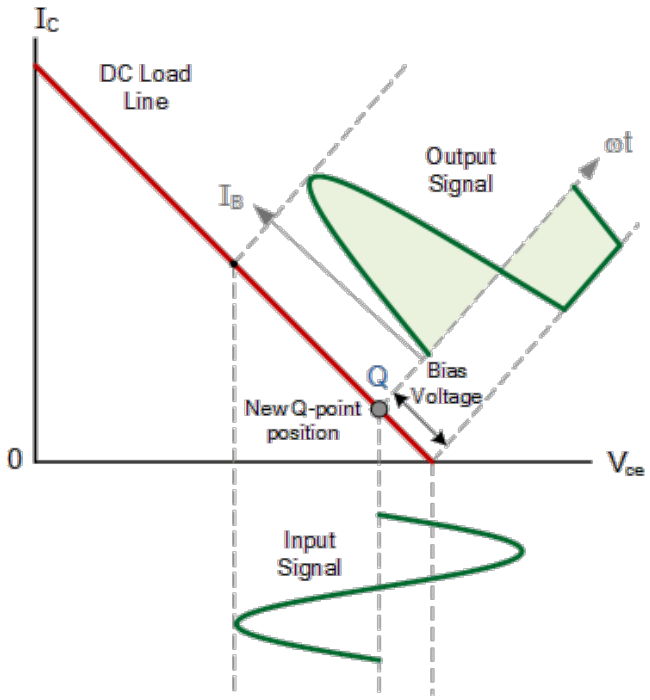


Figure 44: http://www.electronics-tutorials.ws

- **Class B Amplifier**

The characteristic of this type of amplifiers is that the polarization of the valve grid coincides with the cut voltage. That is, having the valve at rest without excitation, Ip = 0, the plate current flows only for half a cycle. The distortion can be moderate and the performance reaches 0.7. These amplifiers are used in power steps of radiotelegraphy stations.

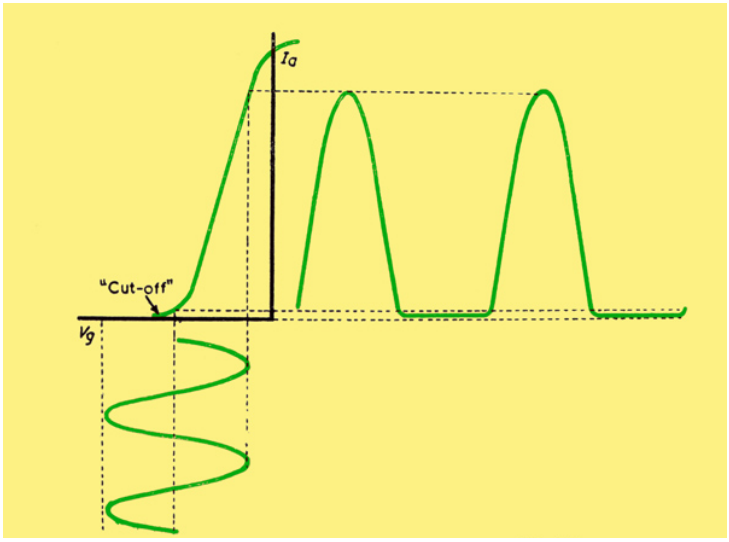


Figure 45: http://www.r-type.org/articles/art004bv.jpg

- **Class C Amplifier**

In this case we have that the polarization of the grid is greater than the value of the cut-off voltage. Hence, the current is zero, Ip = 0, when there is no excitation and flows for less than half a cycle. The distortion can be great, but the performance is very good, being able to reach 90%.

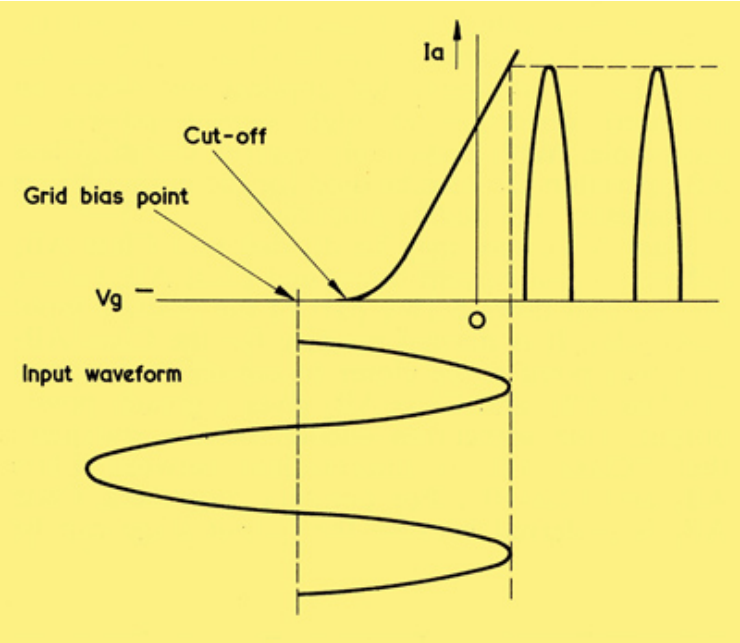


Figure 46: http://www.r-type.org/

In the following figure, we can see the different regions for the different types of amplifiers all together in one single graph:

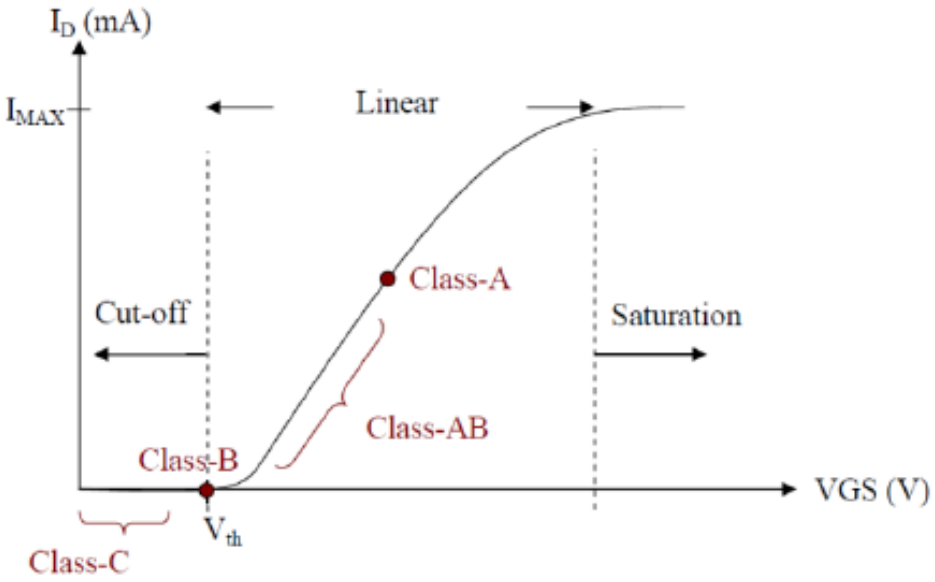


Figure 47: https://www.researchgate.net

- **Tetrode Valve**

A Tetrode Valve is a four-electrode valve. In addition to the cathode, control grid (g1) and plate, like the triode, a new grid is added between the plate and the control grid which we call the screen grid.

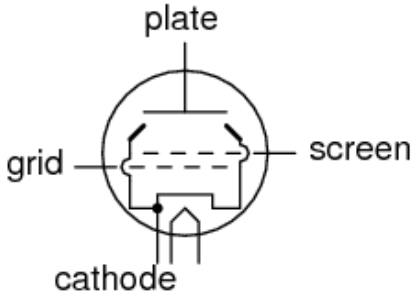


Figure 48: www.ibiblio.org/

There are some advantages when using this valve, but also some detrimental effects are derived, one of which, the effect "secondary emission", produces when the plate voltage is lower than that of the screen. This disadvantage forces the application of strong plate stresses and greatly limits the use of the tetrode.

- **Pentode Valve**

The Pentode Valve is a five-electrode valve, which differs only from the tetrode in that a new grid, the suppressor grid, is added between the plate and the screen grid.

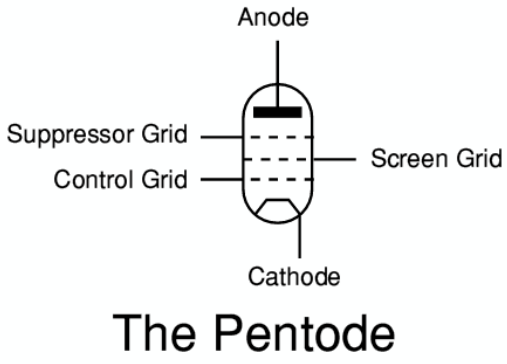


Figure 49: www.st-andrews.ac.uk

The suppressor grid is electrically attached to the cathode and thus repels the electrons producing the "secondary emission", returning them to the plate and thereby eliminating the emission which is so damaging to the tetrode.

We can say that the pentode retains to a greater degree all the advantages of the tetrode, in relation also with the triode, and eliminates its disadvantages thanks to the inclusion of the suppressor grid. In addition to the diode, triode, tetrode and pentode, there are other valves with higher number of electrodes.

Now that we know how valves work, we are going to describe the theory and implementation of a mono audio amplifier using one valve.

- **Mono Amplifier with one valve**

The design is based on the schematic we saw before:

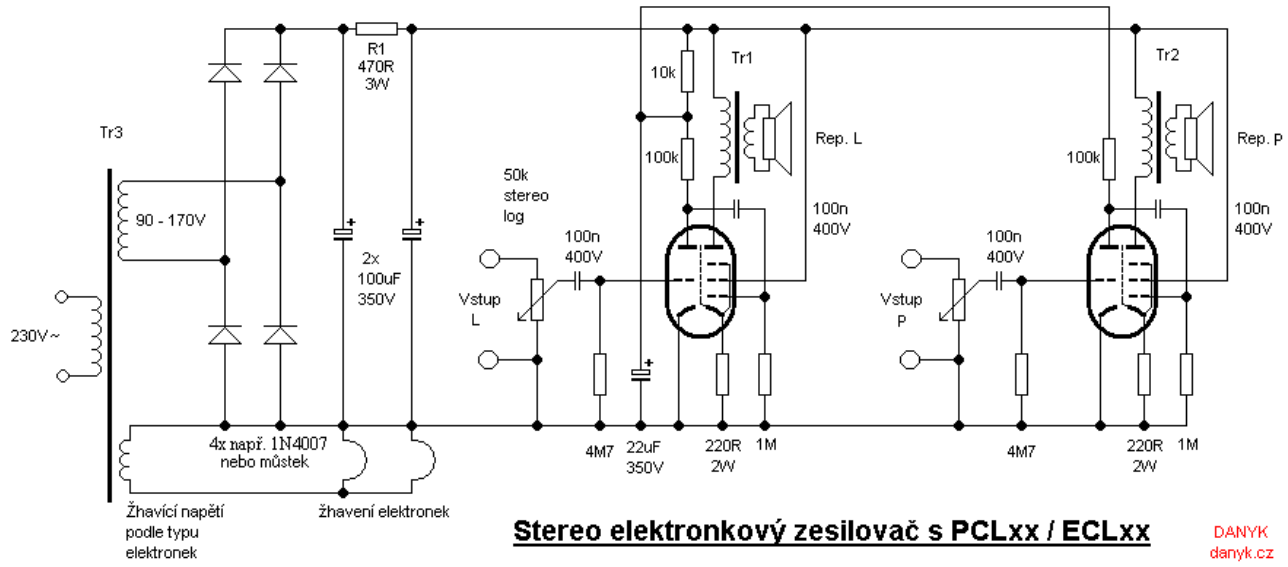


Figure 50: http://danyk.cz/

It is a simple Stereo Amplifier based on two valves, one for each channel. We will use only one channel, making it mono.

- **Implementation of the Mono Amplifier with one valve**

One of the keys of the quality of a valve amplifier is in the output transformer needed before the signal goes to the speaker. If we use a low-quality transformer at this point, we will appreciate a loss in the quality of the sound. We used a high-quality transformer to obtain great quality. We used an Acrosound transformer which have these characteristics. I include here a paragraph taken from the Acrosound transformer manual:

Transformer design has been called an art rather than a science. This indicates that two designers striving for a given level of performance will probably attempt to achieve it in two different ways. Likewise, they will set two different ceilings to their achievable levels of quality. Acrosound Ultra-Linear transformers have been designed for a level of performance which most designers believed unattainable at a competitive price. The methods by which the designs have been achieved are unique and are protected by United States patents, with foreign patents pending. Acrosound transformers are *better* transformers, and there are good reasons for this superiority.

Figure 51: Acrosound Transformer Manual

For the power supply of the circuit, we used two transformers, one for the filament Voltage, which is an adjustable source of 5V, and a transformer of 220V-125V to give voltage to the plates.

We needed to introduce a feedback network that came from the following design, in order to remove some oscillations at certain frequencies:

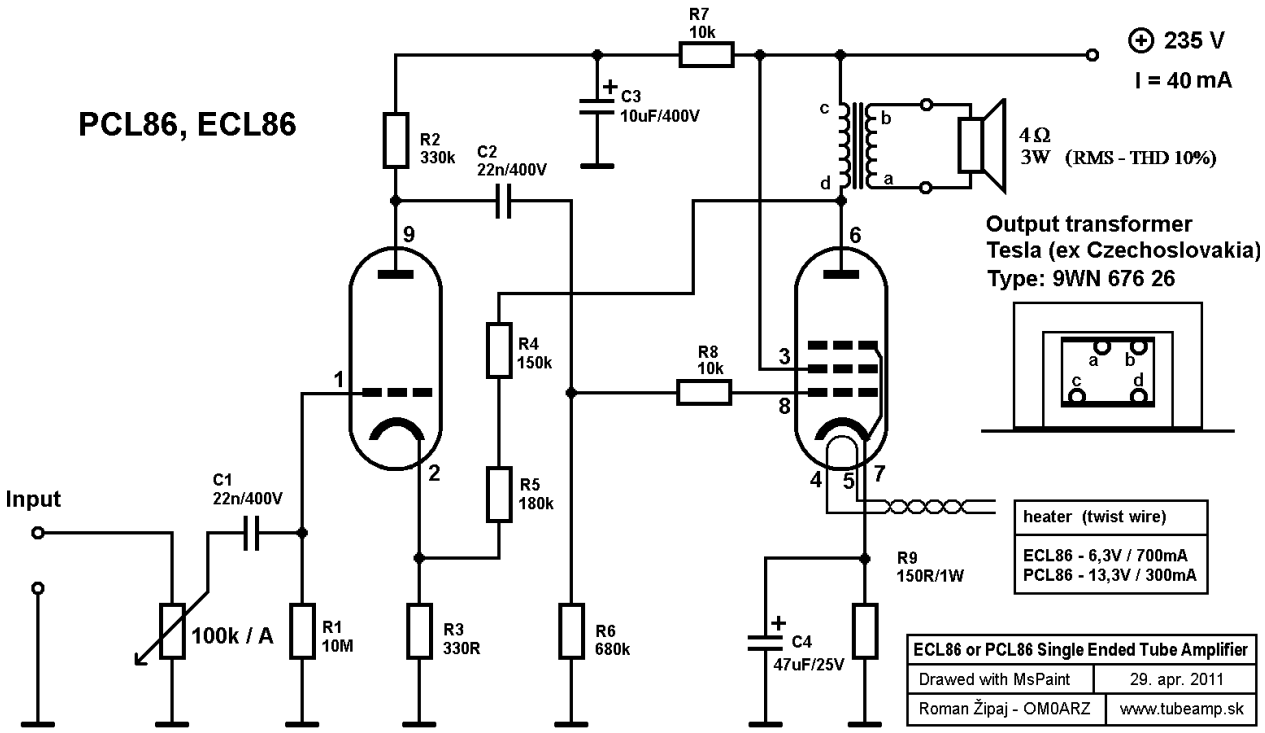


Figure 52: http://www.tubeamp.sk

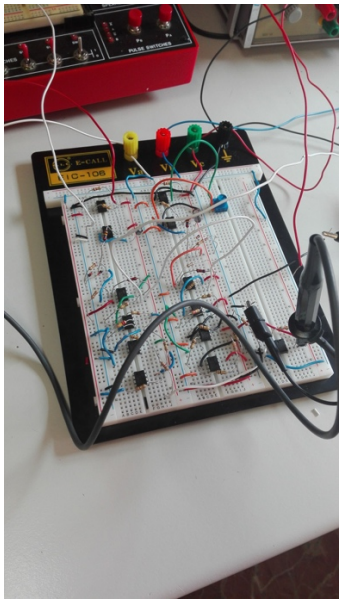
The power of the amplifier depends on the power of the output transformer and the power supported by the valve. With our ECL85 valve we can achieve a maximum power around 6 or 9 Watts.

We will need to do the so called Bias Adjustment, if we use the amplifier for a long time, to have the system working in the proper region of the dynamic curve we saw before. It consists of checking if the Bias Point of the amplifier is in its proper position or we need to replace some component or check any source or transformer.

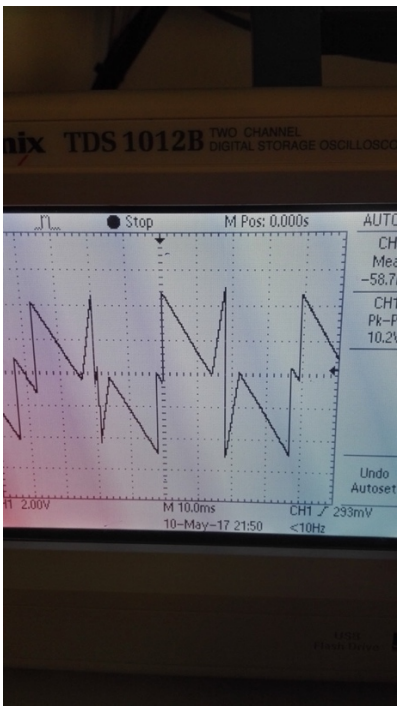
4. EXPERIMENTAL RESULTS

- Signal Processor

Here we have the circuit already assembled and being tested in the protoboard:



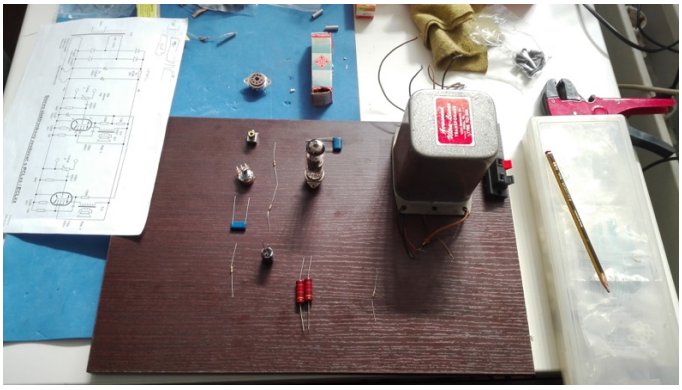
And here an example of the output signal of the system for a saw-tooth input signal:

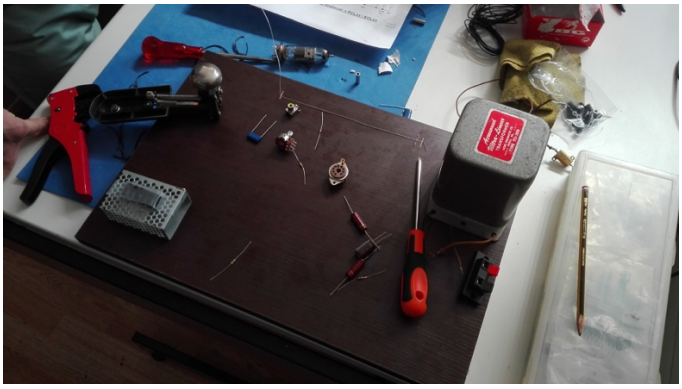


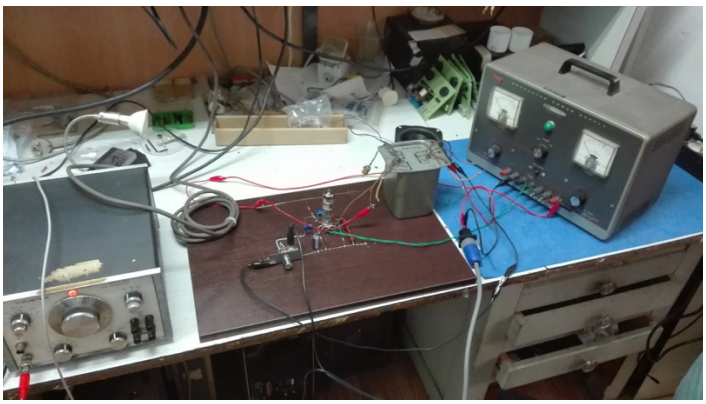
We obtained a good sounding signal processor that creates an effect for any input signal. We can modify the rate of the phase shift by using two potentiometers, one on each part of the circuit we saw before. This rate is adjustable for both phase-shifted replicas, so we are gaining flexibility with respect to the original circuit by Arturia.

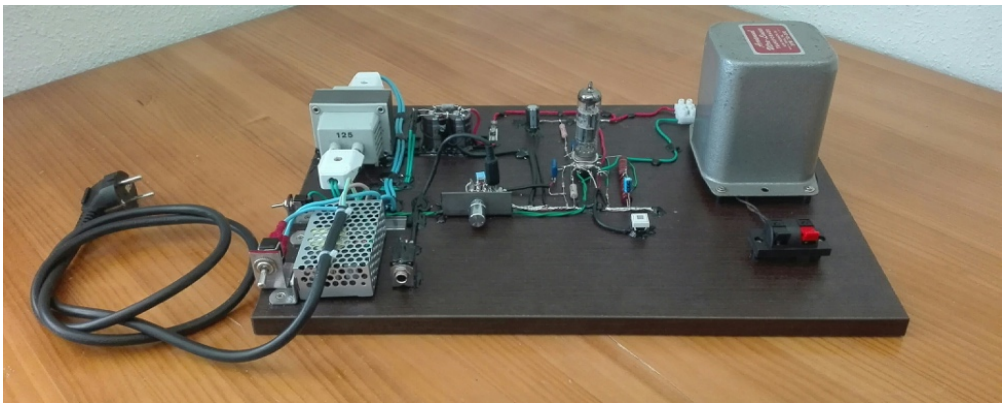
- **Valve Amplifier**

The whole process for mounting the valve amplifier prototype from scratch:









The amplifier works and sounds with good quality either with an instrument or a signal coming from any standard output like the headphones output of a radio or a phone. We checked the correct operation with a guitar, a radio and a phone, and the results were great. It has great power and quality of sound.

We added a switch to activate or deactivate the feedback network to show that the oscillations we found can be removed.

5. CONCLUSIONS AND FUTURE PROPOSALS

Finally, we have our whole system built and working. As we said can the system can be used for many audio applications. If we want to use it for a very specific application we can adjust the values of the circuit components to adapt the system for that purpose.

A future proposal would be to create a second version of both systems but usable for any consumer as a product that could be sold and that accomplish the standards given by the CE rules we saw.

Another proposal would be to design and build more complex systems for audio applications. For example, we could build a valve based reverb, an analog delay, a distorted amplifier, a step sequencer or an arpeggiator to control an analog synthesizer using MIDI or USB connections, an octaver effect that changes the frequency of our signal by bringing it up or down one octave, a pitch modulator to control the pitch of a signal.

6. BIBLIOGRAPHY

[1] Arturia Minibrute Manual

[2] Triangle Wave Generator: https://forum.allaboutcircuits.com/

[3] Hack A Brute: http://hackabrute.yusynth.net/

[4] Valve Amplifier: http://danyk.cz/

[5] Vacuum Valve: http://sonitube.es/

[6] European Commission website: https://ec.europa.eu/

[7] http://www.ce-marking.org/what-is-ce-marking.html

[8] ECL85 Datasheet:

http://www.datasheetspdf.com/PDF/ECL85/1038940/1

7. ATACHMENTS

- **First proposal for the Project**

When I first started this project, my purpose was to design and assembly an Analog Synthesizer. After some time, I discovered that another schoolmate had already designed one for his Bachelor Thesis, so, I talked to him and I decided to complete his system with new things instead of repeating the same work he had already done. It finally was a great idea because I learned from all his experience and I designed a system which can be used together with an analog synth or any other instrument, even we could use it for more applications like voice or any audio signal that we want to process and modify.

Here I include the first document I gave to my professor:

DESIGN AND ASSEMBLY OF AN ANALOG SYNTHESIZER

Overview

The goal of this project is to design and build an analog synthesizer. The purpose is to assembly an electronic musical instrument that can be played. It will be able to generate signals like a sine, square, triangular or saw tooth waveforms, modify them with a filter, amplify them, add effects and finally send them to the output. The output will consist of an analog line output and headphones. In this way, it will have the possibility of being connected to any device with a line input like an amplifier, a mixer or an external sound interface controlled by a computer with a DAW (Digital Audio Workstation). At least in the beginning, the synthesizer will be monophonic, but if it is possible, it will be polyphonic, depending on the complexity found at the beginning of the project.
The main parts of the design will be the following:

- **Oscillator/VCO:** we will need a circuit to produce the initial signal that will generate the sound. There will be more than one type of waveform so we will need an oscillator, a VCO and maybe other circuits to make it.
- **Filter/VCF:** Voltage Controlled Filter to remove the unwanted parts of the signal. It can have a band pass filter, low pass filter and high pass filter.
- **FX unit:** to introduce some effects like reverb or delay to the signal, so it doesn't sound so dry.
- **Amplifier/VCA:** Voltage Controlled Amplifier with controllable gain to give the desired level at the output.
- **ADSR:** to produce the envelope of the signal. There may be more than one to control the filter and the amplifier envelopes.
- **Keyboard:** to play the instrument and select the frequency that the synthesizer generates every time. We will need at least one octave, but two or more would better. It can include some buttons to increase or decrease the octave and also pitch and modulation modifiers.
- **LFO:** Low Frequency Oscillator to generate variations on the signal like vibrato or tremolo for example.
- **Noise:** It can include a noise generator.

Complete system scheme:

In the following figure, we can see the basic scheme of the synthesizer. It is an initial plot, so the final one could have some modifications in order to achieve a better performance.

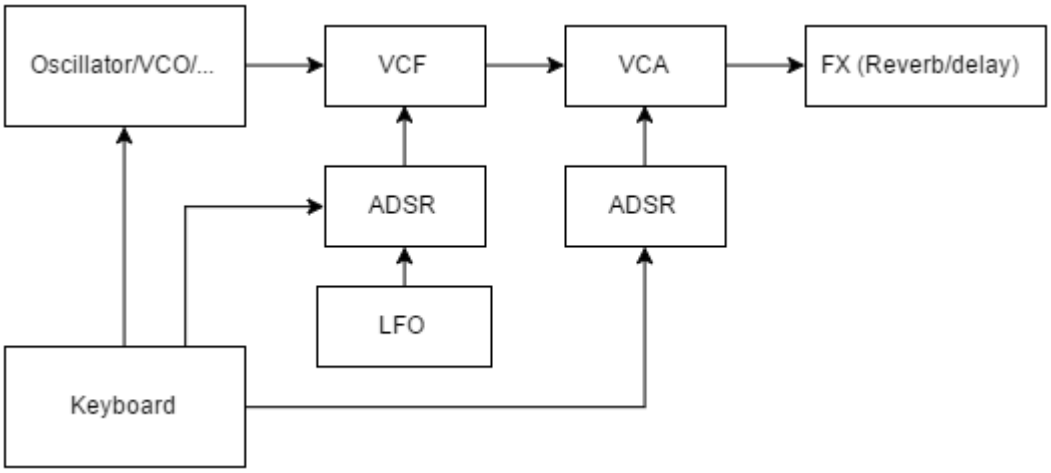

Oscillator/VCO/...
VCF
VCA
FX (Reverb/delay)
ADSR
ADSR
LFO
Keyboard

Figure 53